EX. A

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Yang

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(54) **SYNCHRONOUS RECTIFICATION CIRCUIT FOR POWER CONVERTERS**

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H02M 7/217 (2006.01)

(52) **U.S. Cl.** **363/89**; 363/127

(58) **Field of Classification Search** 363/89, 363/127

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,995,991 B1 2/2006 Yang et al.
2008/0037302 A1* 2/2008 Yang 363/127

* cited by examiner

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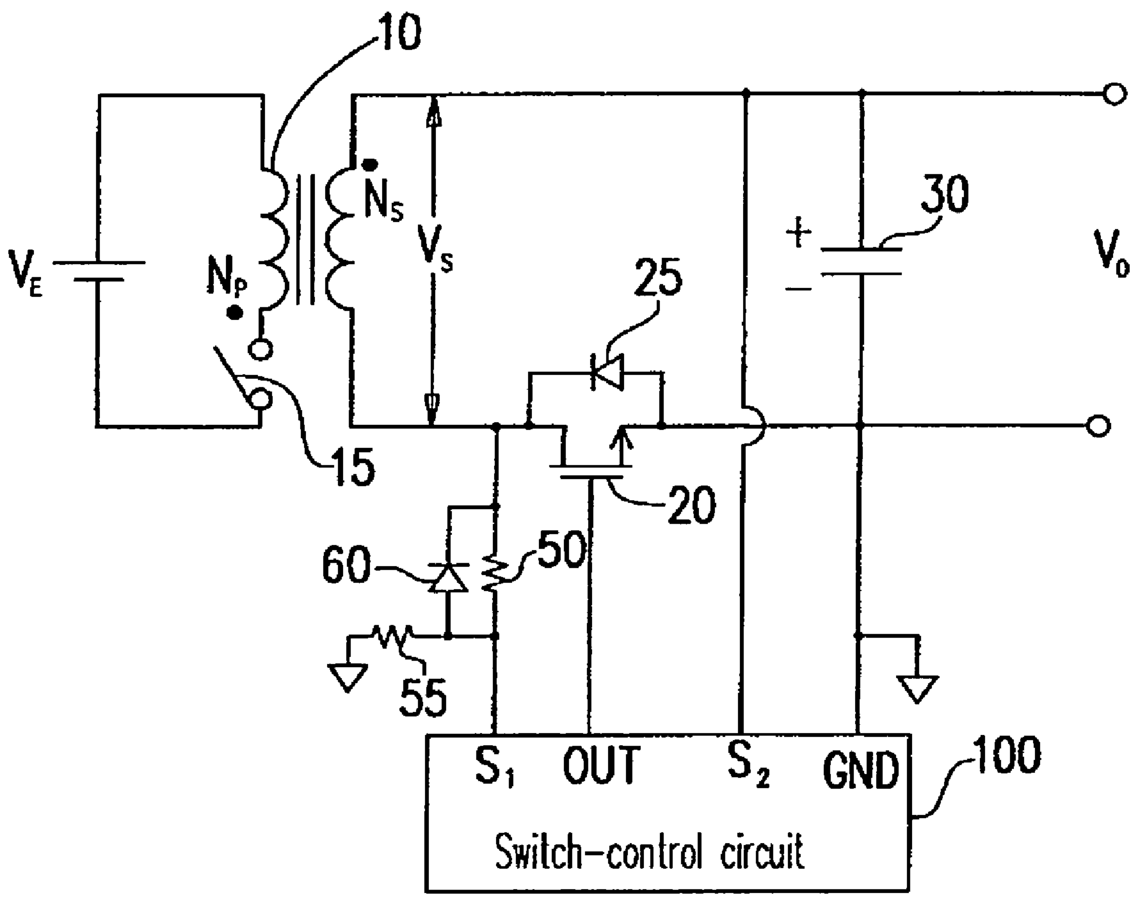
(57) **ABSTRACT**

A synchronous rectification circuit for power converters operable under fixed and/or variable frequencies where no current sense circuit or phase-lock circuit are needed is provided. It has a power switch coupled to a transformer for the rectification. A signal-generation circuit is used for generating a control signal in response to a magnetized voltage of the transformer, a demagnetized voltage of the transformer, and a magnetization period of the transformer. The control signal is coupled to turn on the power switch. The enable period of the control signal is correlated to a demagnetization period of the transformer.

11 Claims, 5 Drawing Sheets



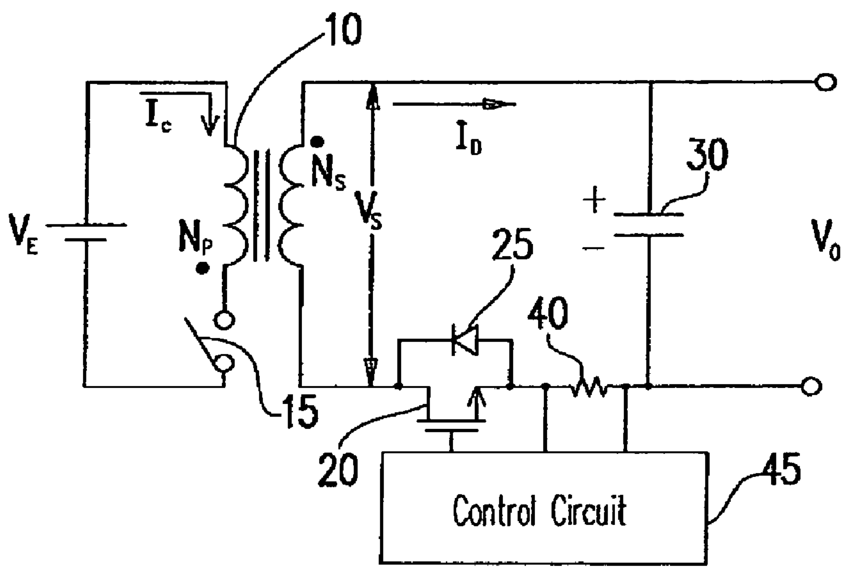


FIG. 1 (PRIOR ART)

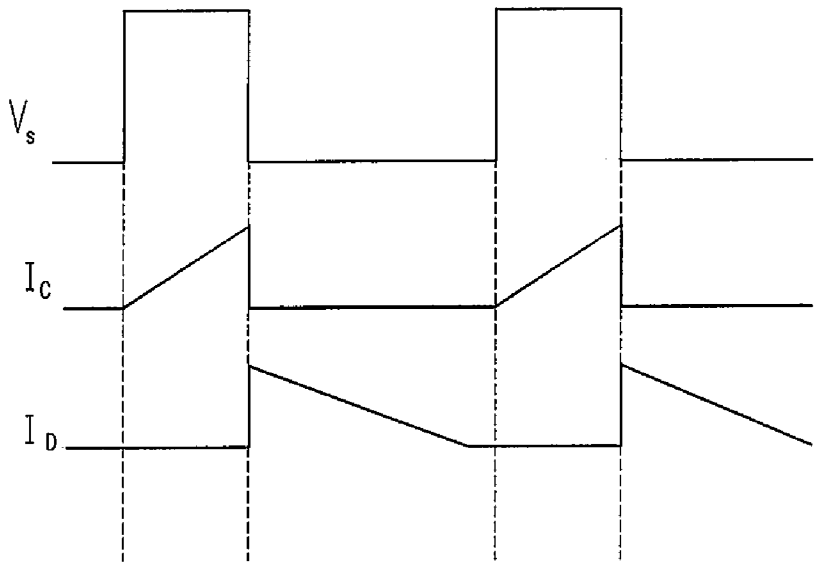


FIG. 2A

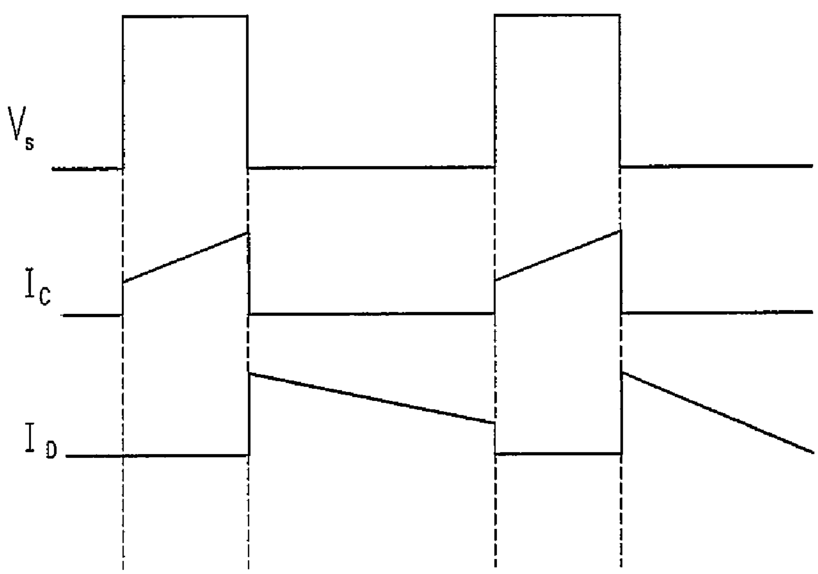


FIG. 2B

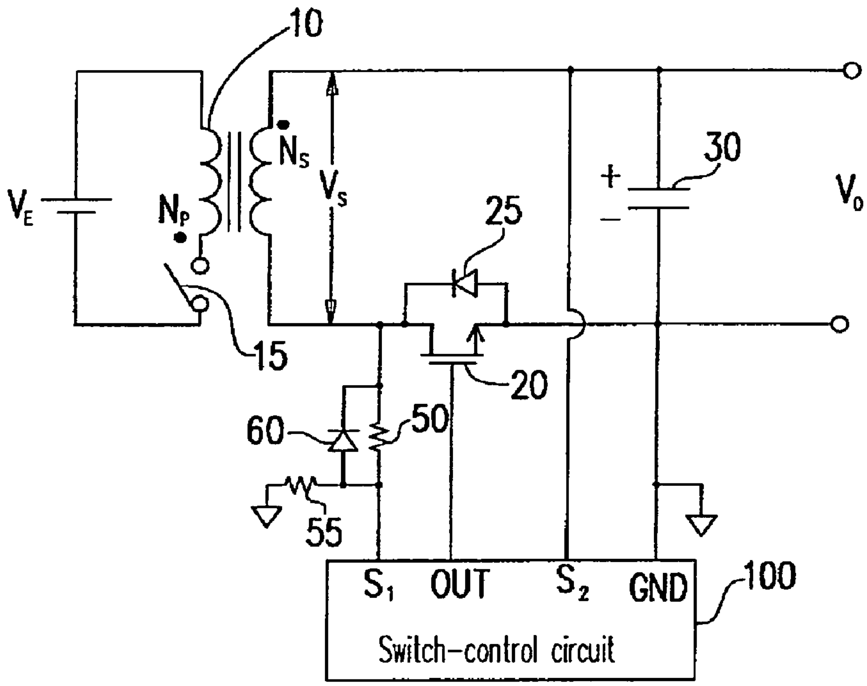

10
N_S
V_S
30
+
−
V_O
V_E
N_P
25
15
20
60
50
55
S_1
OUT
S_2
GND
100
Switch-control circuit

FIG. 3

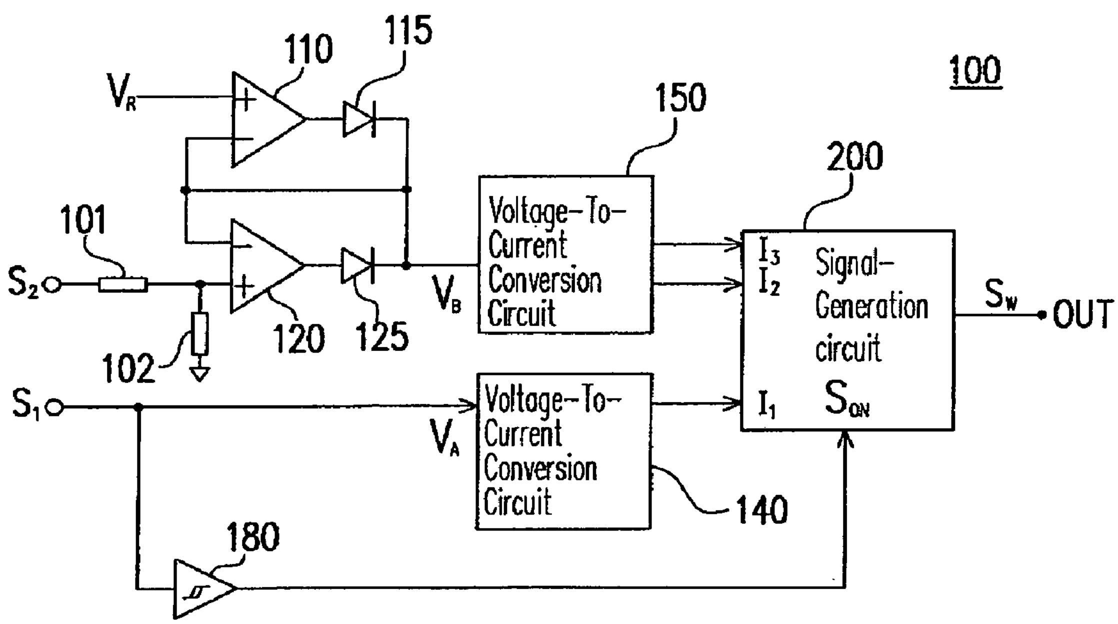
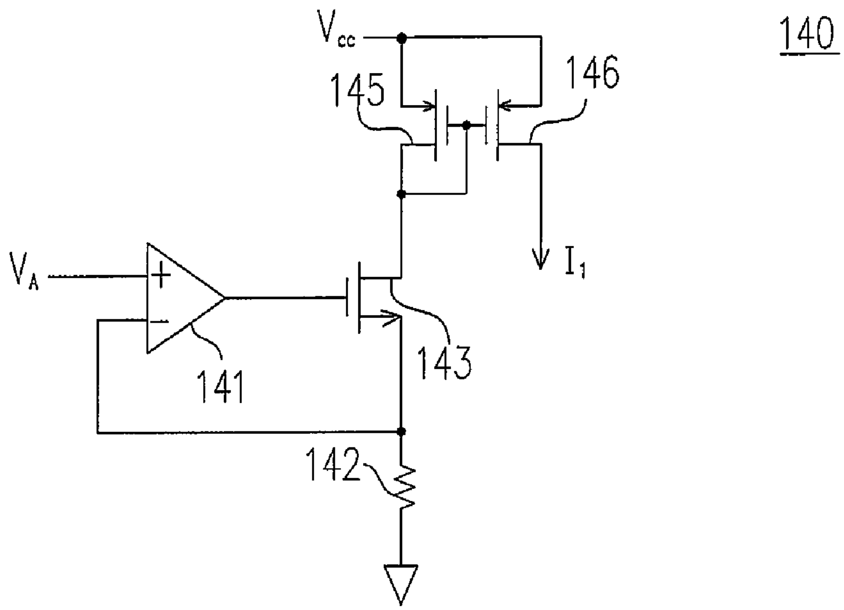
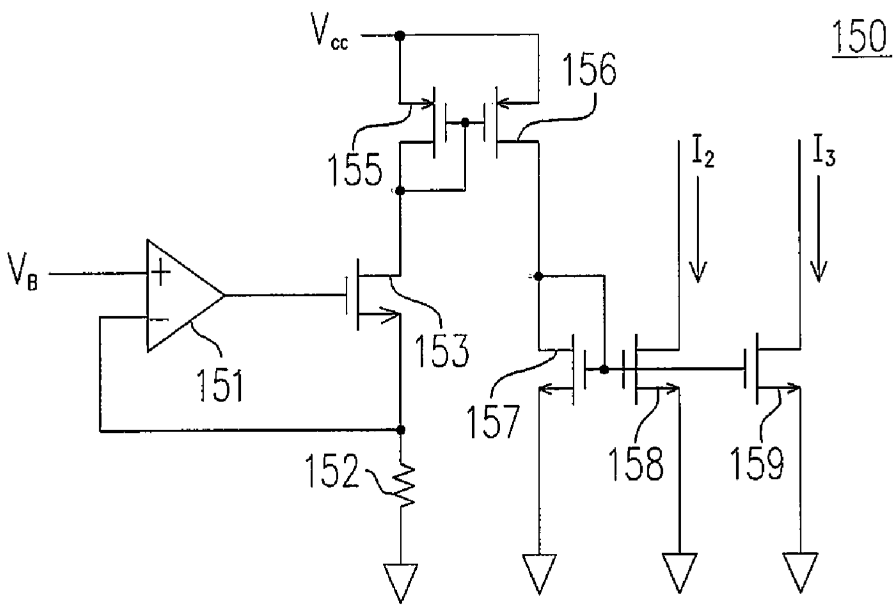

115
110
V_R
100
150
200
101
S_2
V_B
Voltage-To-Current Conversion Circuit
I_3
I_2
Signal-Generation circuit
S_W
OUT
102
120
125
S_1
V_A
Voltage-To-Current Conversion Circuit
I_1
S_{ON}
140
180

FIG. 4



140
V_{cc}
145
146
V_A
+
−
141
143
I_1
142

FIG. 5



150
V_{cc}
156
155
I_2
I_3
V_B
+
−
151
153
157
158
159
152

FIG. 6

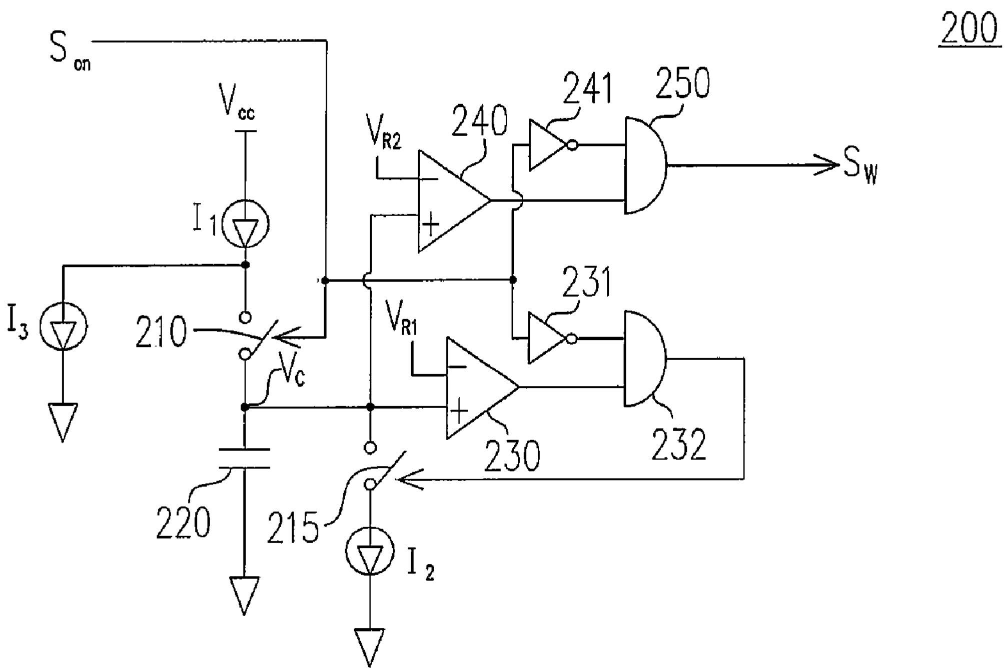

200
S_{on}
V_{cc}
I_1
I_3
210
V_C
220
215
I_2
V_{R2}
240
241
250
S_W
231
V_{R1}
230
232

FIG. 7

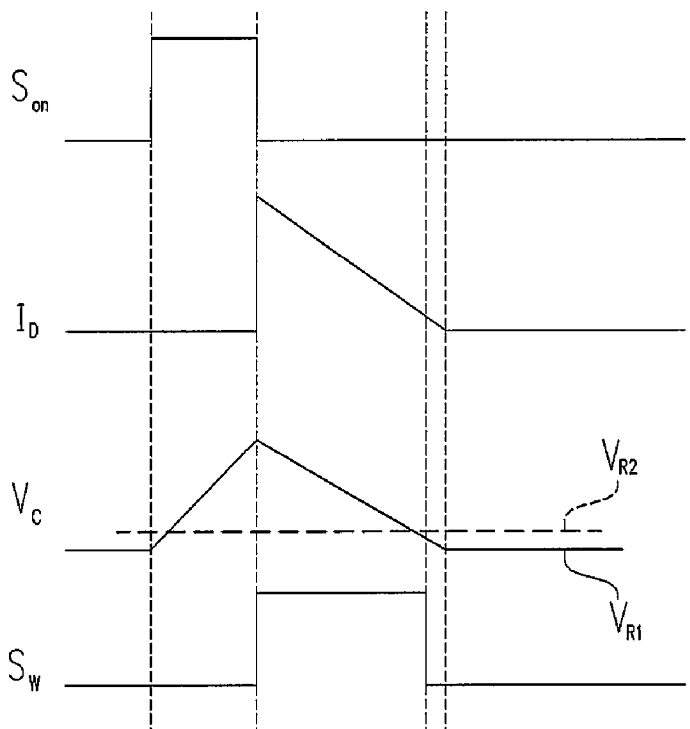

S_{on}
I_D
V_C
V_{R2}
V_{R1}
S_W

FIG. 8

SYNCHRONOUS RECTIFICATION CIRCUIT FOR POWER CONVERTERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to power converter, and more specifically relates to a control circuit of switching power converter.

2. Description of Related Art

FIG. **1** shows a traditional power converter with a synchronous rectifier, for improving the efficiency of power conversion. A magnetic device such as a transformer **10** includes a primary winding N_P and a secondary winding N_S. A switch **15** is connected to the primary winding N_P for switching the transformer **10** and for regulating the output of the power converter. The secondary winding N_S is coupled to the output of the power converter through a power switch **20** and a capacitor **30**. The power switch **20** and its body diode **25** are operated as the synchronous rectifier. A voltage V_E is applied to the primary winding N_P in response to the turning-on of the switch **15** during the magnetization period. Therefore, a charge current I_C is generated in accordance with the voltage V_E and inductance of the primary winding N_P. Meanwhile, a magnetized voltage V_S is produced at the secondary winding N_S. Once the switch **15** is turned off, the energy of the transformer **10** is delivered to the output of the power converter through the secondary winding N_S and the power switch **20**. A demagnetized voltage (the output voltage V_O) is thus applied to the secondary winding N_S during the demagnetization period. A discharge current I_D is generated according to the demagnetized voltage and the inductance of the secondary winding N_S.

$$I_C = \frac{V_E}{L_P} \times T_{CHARGE} \tag{1}$$

$$I_D = \frac{V_O}{L_S} \times T_{DISCHARGE} \tag{2}$$

where L_P and L_S are the inductances of the primary winding N_P and the secondary winding N_S of the transformer **10**, respectively. T_{CHARGE} is the magnetization period; and $T_{DISCHARGE}$ is the demagnetization period.

In continuous current mode (CCM) operation, the switch **15** is turned on before the transformer **10** is completely demagnetized. Under the discontinuous current mode (DCM), the energy in the transformer **10** is fully demagnetized before the start of the next switching cycle. FIGS. **2**A and **2**B show the waveforms of the DCM and CCM, respectively. If the power switch **20** is not turned off after the transformer **10** is fully demagnetized, a reverse current will be flowed to the power switch **20** to discharge the capacitor **30**. This reverse current decreases the efficiency of the power converter. In order to avoid the reverse current, a conventional method had been proposed for the synchronous rectification, such as in "PWM controller for synchronous rectifier of flyback power converter" by Yang et al., U.S. Pat. No. 6,995,991. A resistor **40** and its control circuit **45** are used to turn off the power switch **20** once the discharge current I_D is lower than a threshold value. Furthermore, a phase-lock circuit is equipped to turn off the power switch **20** before the start of the next switching cycle during the CCM operation. Nevertheless, the current detection and the phase-lock circuit produce power losses and add complexity to the system. Furthermore, a wide variable frequency system, such as a resonant power converter, causes problems for phase locking.

SUMMARY OF THE INVENTION

The present invention provides a synchronous rectification circuit that is applicable for use in power converters operating under fixed frequency and/or variable frequency. No current sense circuit or phase-lock circuit is needed. The synchronous rectification circuit comprises a power switch coupled to a transformer (a magnetic device) for the rectification. A signal-generation circuit is used for generating a control signal in response to a magnetized voltage of the transformer, a demagnetized voltage of the transformer, and a magnetization period of the transformer. The control signal is coupled to turning on the power switch. The enable period of the control signal is correlated to a demagnetization period of the transformer. Furthermore, the control signal is increased in response to the increase of the magnetized voltage. The control signal is decreased in response to the decrease of the magnetization period of the transformer. Besides, the control signal is decreased in response to the increase of the demagnetized voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide further understanding of the invention, and are incorporated into and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. **1** shows a traditional power converter with synchronous rectifier.

FIGS. **2**A and **2**B show the waveforms of the DCM and CCM, respectively.

FIG. **3** shows a power converter including a synchronous rectification circuit in accordance with an embodiment of the present invention.

FIG. **4** shows a switching-control circuit according to the embodiment of the present invention.

FIGS. **5** and **6** show the schematics of a plurality of voltage-to-current conversion circuits according to the embodiment of the present invention.

FIG. **7** shows a signal-generation circuit according to the embodiment of the present invention.

FIG. **8** shows a plurality of waveforms of the synchronous rectification circuit in accordance with the embodiment of the present invention.

DESCRIPTION OF THE EMBODIMENTS

FIG. **3** shows a switching power converter comprising a synchronous rectification circuit in accordance with an embodiment of the present invention that is applicable for use in power converters operating under fixed frequency and/or variable frequency. No current sense circuits or phase-lock circuits are needed. The power switch **20** is coupled to the transformer **10** (the magnetic device) for the rectification. A switching-control circuit **100** is used for generating a control signal S_W in response to a magnetized voltage V_S, a demagnetized voltage, and a magnetization period of the transformer **10**. The control signal S_W is coupled to turn on the power switch **20**. The enable period of the control signal S_W is correlated to a demagnetization period of the transformer.

When the switch **15** is turned on, a voltage V_{DS} is produced in between the secondary winding N_S and the power switch

20. The voltage V_{DS} is related to the magnetized voltage (V_S) of the transformer **10**.

$$V_S = V_{DS} - V_O \tag{3}$$

When the switch **15** is turned off, the output voltage V_O is applied to the secondary winding N_S for the demagnetization. The output voltage V_O is thus correlated to the demagnetized voltage of the transformer **10**. An input terminal S_1 of the switching-control circuit **100** is coupled to detect the voltage V_{DS} through a plurality of resistors **50** and **55**. A diode **60** is further coupled to the secondary winding N_S to speed up the detection of the voltage V_{DS}. Another input terminal S_2 is coupled to the output of the power converter for receiving the output voltage V_O.

The magnetization flux Φ_C of the transformer is equal to the demagnetization flux Φ_D. The equality is shown as,

$$\Phi_C = \Phi_D \tag{4}$$

$$\Phi = B \times Ae = \frac{V \times T}{N} \tag{5}$$

$$\frac{V_E}{N_P} \times T_{CHARGE} = \frac{V_O}{N_S} \times T_{DISCHARGE} \tag{6}$$

$$V_E \times T_{CHARGE} = \frac{N_P}{N_S} \times V_O \times T_{DISCHARGE} \tag{7}$$

$$V_E = \frac{N_P}{N_S} \times V_S \tag{8}$$

where B is the flux density, Ae is the cross-section area of the transformer, T is the magnetization period (T_{CHARGE}) or the demagnetization period ($T_{DISCCHARGE}$) of the transformer, and N is the number of winding turns of the transformer.

The demagnetization period ($T_{DISCHARGE}$) of the transformer **10** can be obtained in accordance with equations (7) and (8).

$$T_{DISCHARGE} = \frac{V_S}{V_O} \times T_{CHARGE} \tag{9}$$

The equation (9) shows that the demagnetization period ($T_{DISCHARGE}$) can be predicted in accordance with the magnetized voltage V_S, the demagnetized voltage V_O, and the magnetization period (T_{CHARGE}). According to the equations (3) and (9), the demagnetization period ($T_{DISCHARGE}$) can be rewritten as the following:

$$T_{DISCHARGE} = \frac{(V_{DS} - V_O)}{V_O} \times T_{CHARGE} \tag{10}$$

The enable period of the control signal S_W is generated in accordance with the demagnetization period ($T_{DISCHARGE}$) of the transformer **10**. Therefore, the enable period of the control signal S_W is increased in response to the increase of the magnetized voltage V_S. The enable period of the control signal S_W is decreased in response to the decrease of the magnetization period (T_{CHARGE}) of the transformer **10**. Besides, the enable period of the control signal S_W is decreased in response to the increase of the demagnetized voltage V_O.

FIG. **4** shows the switching-control circuit **100** according to an embodiment of the present invention. An input circuit includes a plurality of operational amplifiers **110**, **120**, diodes **115**, **125**, voltage-to-current conversion circuits **140**, **150**, resistive devices **101**, **102**, and a hysterias-buffer circuit **180**. The operational amplifier **110** and the diode **115** form a first unit-gain buffer supplied by the reference signal V_R. The operational amplifier **120** and the diode **125** form a second unit-gain buffer coupled to the input terminal S_2 through the resistive devices **101** and **102**. The output of the first unit-gain buffer and the output of the second unit-gain buffer are tied together to generate the signal V_B. The reference signal V_R clamps the minimum value of the signal V_B. The signal V_B is connected to the voltage-to-current conversion circuit **150** to generate a second signal I_2, and a third signal I_3 in response to the output voltage V_O. The minimum value of the second signal I_2 is clamped to a limit value. The input terminal S_1 produces a voltage signal V_A that is connected to the voltage-to-current conversion circuit **140** to generate a first signal I_1 in response to the voltage V_{DS}. Furthermore, the hysterias-buffer circuit **180** is coupled to the input terminal S_1 to generate a switching signal S_{ON} in response to the magnetization period of the transformer **10**. The first signal I_1, the second signal I_2, the third signal I_3, and the switching signal S_{ON} are coupled to the signal-generation circuit **200** to generate the control signal S_W.

FIGS. **5** and **6** show the voltage-to-current conversion circuits **140** and **150** according to the embodiment of the present invention, respectively. The voltage V_A is connected to an operational amplifier **141**. The operational amplifier **141** is connected to a transistor **143** and a resistor **142** for generating a current I_{143} in response to the voltage V_A. The current I_{143} is connected to a plurality of transistors **145** and **146** to generate the first signal I_1. The voltage V_B is connected to an operational amplifier **151**. The operational amplifier **151** is connected to a transistor **153** and a resistor **152** for generating a current I_{153} in response to the voltage V_B. The current I_{153} is connected to a plurality of transistors **155** and **156** to generate a current I_{156}. The current I_{156} is further connected to a plurality of transistors **157**, **158** and **159** for generating the second signal I_2 and the third signal I_3. Therefore the first current I_1 is generated in accordance with the voltage V_A. The second signal I_2 and the third signal I_3 are generated in accordance with the voltage V_B.

FIG. **7** shows the signal-generation circuit **200**. A capacitor **220** is utilized to determine the period of the control signal S_W. A first switch **210** is coupled in between the first signal I_1 and the capacitor **220**. A second switch **215** is coupled in between the second signal I_2 and the capacitor **220**. A first comparator **230** is coupled to the capacitor **220** for generating a first-control signal at the output of the first comparator **230** once the voltage of the capacitor **220** is higher than a first reference voltage V_{R1}. An output circuit formed by an inverter **231** and an AND gate **232** is coupled to generate a first discharge signal at the output of the AND gate **232** in response to the enabling of the first-control signal and the disabling of the switching signal S_{ON}. The switching signal S_{ON} is further coupled to control the first switch **210**. The first switch **210** is turned on in response to the enabling of the switching signal S_{ON} The first discharge signal is coupled to control the second switch **215**. The second switch **215** is turned on in response to the enabling of the first discharge signal. The first signal I_1 is used for charging the capacitor **220**. The second signal I_2 is utilized for discharging the capacitor **220**. The third signal I_3 is further coupled to the first signal I_1 to decrease the value of the first signal I_1.

The voltage V_{DS} determines the first signal I_1. The first signal I_1 can be expressed as,

$$I_1 = k1 \times \frac{V_{DS}}{R_{142}} \tag{11}$$

The output voltage V_O determines the second signal I_2 and the third signal I_3 as the following:

$$I_2 = k2 \times \frac{V_O}{R_{152}} \tag{12}$$

$$I_3 = k3 \times \frac{V_O}{R_{152}} \tag{13}$$

The voltage on the capacitor **220** can be expressed as,

$$V_C = \frac{I_1 - I_3}{C} \times T_{ON} = \frac{\frac{k1 \times V_{DS}}{R_{142}} - \frac{k1 \times V_O}{R_{152}}}{C} \times T_{ON} \tag{14}$$

where k1, k2 and k3 are constants such as the ratio of resistive devices and/or the gain of current mirror, C is the capacitance of the capacitor **220**, T_{ON} is enable time of the switching signal S_{ON} (the charge time of the capacitor **220**), R_{142} is the resistance of the resistor **142**, and R_{152} is resistance of the resistor **152**. The discharge time T_{OFF} of the capacitor **250** is given by,

$$T_{OFF} = \frac{C \times V_C}{I_2} = \frac{C \times V_C}{k2 \times \frac{V_O}{R_{152}}} \tag{15}$$

By properly selecting k1, k2, k3, R_{142}, and R_{152}, the discharge time T_{OFF} of the capacitor **250**, can be rewritten according to equations (14) and (15):

$$T_{OFF} = K \times \frac{V_{DS} - V_O}{V_O} \times T_{ON} \tag{16}$$

The discharge time T_{OFF} of the capacitor **250** is therefore corresponded to the demagnetization period $T_{DISCHARGE}$ of the transformer **10**.

$$T_{DISCHARGE} = K \times \frac{V_S}{V_O} \times T_{CHARGE} \tag{17}$$

where K is a constant.

A second comparator **240** is coupled to the capacitor **220** to generate a second control signal at the output of the second comparator **240** once the voltage of the capacitor **220** is higher than a second reference voltage V_{R2}. Another output circuit formed by an inverter **241** and an AND gate **250** is coupled to generate a second discharge signal at the output of the AND gate **250** in response to the enabling of the second-control signal and the disabling of the switching signal S_{ON}.

The control signal S_W can be generated in accordance with the first discharge signal or the second discharge signal. The second discharge signal is utilized to generate the control signal S_W in this embodiment. The second reference voltage V_{R2} is higher than the first reference voltage V_{R1}. Therefore, the control signal S_W is disabled and the power switch **20** is turned off before the magnetizing of the transformer **10**.

Referring to equation (16) and the waveforms of the synchronous rectification circuit of FIG. **8**, the period of the control signal S_W is controlled by the discharge time T_{OFF} of the capacitor **250** (the voltage V_C). The period of the control signal S_W is decreased in response to the decrease of the charge time T_{ON} of the capacitor **250**. The period of the control signal S_W is increased in response to the decrease of the output voltage V_O. The charge time T_{ON} is controlled by the enable time of the switching signal S_{ON} which is correlated to the magnetization period (T_{CHARGE}).

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention covers modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A synchronous rectification circuit of the power converter, comprising:

a power switch, coupled to a transformer for rectification; and

a switching-control circuit, generating a control signal in response to a magnetized voltage of the transformer, a demagnetized voltage of the transformer, and a magnetization period of the transformer,

wherein the control signal is coupled to control the power switch, and the enable period of the control signal is correlated to a demagnetization period of the transformer.

2. The synchronous rectification circuit as claimed in claim **1**, wherein the enable period of the control signal is increased in response to the increase of the magnetized voltage, the enable period of the control signal is decreased in response to the decrease of the magnetization period of the transformer, and the enable period of the control signal is decreased in response to the increase of the demagnetized voltage.

3. The synchronous rectification circuit as claimed in claim **1**, wherein the switching-control circuit, comprising:

an input circuit, generating a first signal, a second signal, a third signal and a switching signal; and

a signal-generation circuit, coupled to the input circuit to generate the control signal,

wherein the first signal is correlated to a voltage of the transformer, the second signal and the third signal are correlated to the output voltage of the power converter, and the switching signal is generated in response to the magnetization period of the transformer.

4. The synchronous rectification circuit as claimed in claim **3**, wherein the signal-generation circuit, comprising:

a capacitor;

a first switch, coupled in between the first signal and the capacitor;

a second switch, coupled in between the second signal and the capacitor;

a first comparator, coupled to the capacitor to generate a first-control signal once the voltage of the capacitor is higher than a first reference voltage; and

an output circuit, coupled to generate a first discharge signal in response to the enabling of the first-control signal and the disabling of the switching signal,

wherein the first switch is turned on in response to the enabling of the switching signal, the second switch is turned on in response to the enabling of the first discharge signal, wherein the first signal is used for charging the capacitor, the second signal is utilized to discharge the capacitor, and the third signal is further coupled to the first signal to decrease the value of the first signal.

5. The synchronous rectification circuit as claimed in claim **4**, wherein the signal-generation circuit, further comprising:

a second comparator, coupled to the capacitor to generate a second control signal once the voltage of the capacitor is higher than a second reference voltage, wherein the control signal is generated in accordance with the first discharge signal or a second discharge signal.

6. The synchronous rectification circuit as claimed in claim **3**, wherein the minimum value of the second signal is clamped to a limit value.

7. The synchronous rectification circuit as claimed in claim **1**, wherein the power switch is turned off before the magnetizing of the transformer.

8. A synchronous rectification apparatus for a power converter, comprising:

a power switch, coupled to a magnetic device for rectification; and

a switching-control circuit, generating a control signal coupled to control the power switch in response to a magnetized voltage of the magnetic device and a magnetization period of the magnetic device,

wherein the enable period of the control signal is correlated to a demagnetization period of the magnetic device.

9. The synchronous rectification apparatus as claimed in claim **8**, wherein a demagnetized voltage of the magnetic device is further utilized to determine the enable period of the control signal.

10. The synchronous rectification apparatus as claimed in claim **8**, wherein the enable period of the control signal is increased in response to the increase of the magnetized voltage, the enable period of the control signal is decreased in response to the decrease of the magnetization period of the magnetic device, and the enable period of the control signal is decreased in response to the increase of the demagnetized voltage.

11. The synchronous rectification apparatus as claimed in claim **8**, wherein the power switch is turned off before the magnetizing of the magnetic device.

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